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JAY CARTER ENTERPRISES, INC. STEAM ENGINE

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ABSTRACT

The Small Community Solar Thermal Power Experiment (SCSE) has selected an organic rankine cycle (ORC) engine driving a high speed permanent magnet alternator (PMA) as the baseline power conversion subsystem (PCS) design. The high frequency alternating current from the PMA is rectified and inverted to grid quality electricity. The back-up conceptual PCS design is a Jay Careter steam engine driving an induction alternator delivering power directly to the grid. This paper traces the development of Carter's automotive reciprocating simple rankine cycle steam engine and how an engine of similar design might be incorporated into the SCSE. A description of the third generation automotive engine is included along with some preliminary test data. Tests were conducted with the third generation engine driving an induction alternator delivering power directly to the grid. The purpose of these tests is to further verify the effects of expander inlet temperature, input thermal power level, expansion ratio, and other parameters affecting engine performance to aid in the development of an SCSE PCS.

INTRODUCTION

Early in Phase II of SCSE a fact-finding panel, consisting of personnel from the Jet Propulsion Laboratory, Lewis Research Center, Ford Aerospace and Communications Corp., and the Solar Energy Research Institute, was formed to assess the state-of-the-art in small organic and steam rankine cycle engines. The panel concluded that neither organic nor steam engines of the desired size range were off-the-shelf items and both were at a comparable state of development. After the ORC was selected as the baseline design, a parallel program was initiated to test the Carter third generation automotive engine driving an induction alternator. Testing is currently underway at the Jay Carter Enterprises, Inc. west coast office Santa Barbara, California. Preliminary results are available which will be presented along with a general description of how a Carter engine might be utilized in a solar application.

History of Engine Development

The main office of Jay Carter Enterprises, Inc. (JCE) is located in Burkburnett, Texas and was established in 1968. The first three years at JCE were spent developing inlet steam valves and piston cylinder expanders. A first generation engine was completed in 1971, tested for nine months, and in March, 1972 installed in a 1964 VW Squareback sedan. The maximum expander inlet conditions were 538°C (1,000°F) and 13.79 M Pa (2000 psia). The expander consisted of four radial piston cylinders with 574 cm^3 (35 in^3) displacement and an 11.3:1 expansion ratio (1).

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The VW Squareback sedan with the first generation JCE engine demonstrated exceptional overall vehicle performance. Peak engine power was 52 KW (70 HP) mechanical at 5,000 RPM. Road tests were conducted for 9,700 Km (6,000 miles) at speeds as high as 130 Km/hr (80 miles/hour) and at the end of 3,200 Km (2,000 miles) the engine showed no signs of wear. This automobile had a cold start-up to vehicle moving time capability of less than 15 seconds. This was the first automobile to meet the original 1976 emissions standards without add-on devices and demonstrated the best officially documented fuel mileage for a rankine-powered motor vehicle up to that time (June, 1974)(2, 3).

The second generation engine was developed to operate in a 74 VW Dasher or an AMF designed paratransit vehicle (PTV). Paratransit was defined as all types of transit between privately owned and operated cars on one side and scheduled rail and bus service on the other. The second generation engine expander consisted of two cylinders vertically mounted which delivered 75 KW (100 HP) at 5,500 RPM. The 6.35 cm (2.5 in.) diameter and 7.62 cm (3.0 in.) stroke piston cylinders produced a total engine displacement of 463 cm^3 (30 in^3) and an expansion ratio of 10:1. Expander inlet temperature was held constant at 566°C (1,050°F) while pressure varied up to 17.24 MPa (2,500 psia) approximately proportional to input power level (4).

A third generation engine was built in 1977 which was virtually identical to the second generation engine. One modification incorporated into the third generation engine was screw on heads.

Description of Third Generation Test Engine

The expander on the third generation engine shown schematically in Figure 1 for a solar application consists of two vertically mounted piston-cylinders operating in parallel. Each piston-cylinder has a spring return inlet valve opened by a spike attached to the piston. These valves are commonly referred to as "bash valves". This valve design is a fixed cutoff type meaning a constant volume of steam is admitted into the cylinder at the top of each stroke. Power output from the engine is controlled by varying the boiler pressure which also changes the mass flowrate into the expander. This type of control system requires minimal throttle valve control; however, a positive displacement feed pump with solenoid valving is required to deliver controlled mass flow at variable pressures. Toward the end of each stroke oil is injected directly onto the piston rings to minimize wear and leakage around the rings. The oil is a non-emulsifying oil which is allowed to freely mix with the steam at the expander exhaust. The expander is a uniflow design, meaning that at the end of each stroke the piston uncovers exhaust ports which allow the oil/steam mixture to pass through the feedwater heater and on to the ir-cooled condenser. After the steam is condensed the oil and water are separated using the centrifuge which returns the oil to the expander and the water to an open to atmosphere water tank. The piston type feed pump delivers the water from the water tank through the feedwater heater and back to the boiler.

Test Results

The third generation engine was tested at expander inlet temperatures between 399°C (750°F) and 566°C (1,050°F) and at power levels from 25 to 80 KWth input. Efficiencies as high as 20% were measured, based on net electrical power delivered to the grid divided by the thermal input to the working fluid. All electric power parasitics were subtracted from the alternator output to obtain the net electric output. Preliminary data showing efficiency versus thermal input are plotted in Figure 2 at 538°C (1,000°F) expander inlet temperatures for a 10:1 expansion ratio. These efficiencies could be improved by adding insulation and repairing leaks in the condenser which created an excessive expander back pressure. Testing at a 14 to 1 expansion ratio was initiated; however, the data is not currently available. Engine simulations predict improved efficiencies at this higher expansion ratio.

Engine Solar Applications

JCE completed a preliminary design study evaluating a JCE engine mounted at the focus of a parabolic dish solar collector (5). The study determined that for a 15 KW_e engine/induction alternator unit, a single cylinder expander was optimal for a simple cycle and two cylinders were optimal for a reheat cycle. Maximum design inlet steam temperatures and pressures were 677°C (1,250°F) and 17.2 MPa (2,500 psia). An engine design speed of 3,600 RPM and maximum thermal input of 80 KWth was selected. Under these conditions a simple cycle and a compound reheat cycle had predicted total power conversion efficiencies (thermal-to-electric) of 26 and 30 percent, respectively. This engine would be easily adaptable to a total energy application which would use the high temperature steam to generate electricity and the 100°C (212°F) exhaust heat for domestic, commercial or industrial heating applications. This would increase the total system efficiency to approximately 90%.

Several engine mounting configurations are possible with a JCE engine on a parabolic dish collector. The JCE approach described in the study would mount everything except the condenser and the oil/water separation storage tank at the focal point of the dish. This configuration would have a dish mounted weight of 297 KG (654 lb.) and a total weight of 601 KG (1,323 lb.). The condenser would be fitted with a chimney to minimize parasitic fan power. Other mounting configurations might include using the condenser as a counter weight for the concentrator or simply mounting everything at the focus. Freeze protection could be accomplished with flexible freeze tanks, resistance heaters or a buried water storage tank.

Conclusion

The JCE third generation automotive engine has demonstrated total power conversion efficiencies (thermal to electric) of approximately 20%. The engine test data corresponds closely with the predicted data at several operating conditions which add credibility to the model. Verification of the engine and model through testing indcates predicted 26% simple cycle and 30% reheat cycle thermal to electric efficiencies are achievable at 677°C (1,250°F) for 15 KW_e power levels. The value of this engine in a solar application could be further enhanced by using the 100°C (215°F) exhaust heat, thus increasing the total system efficiency to approximately 90%.

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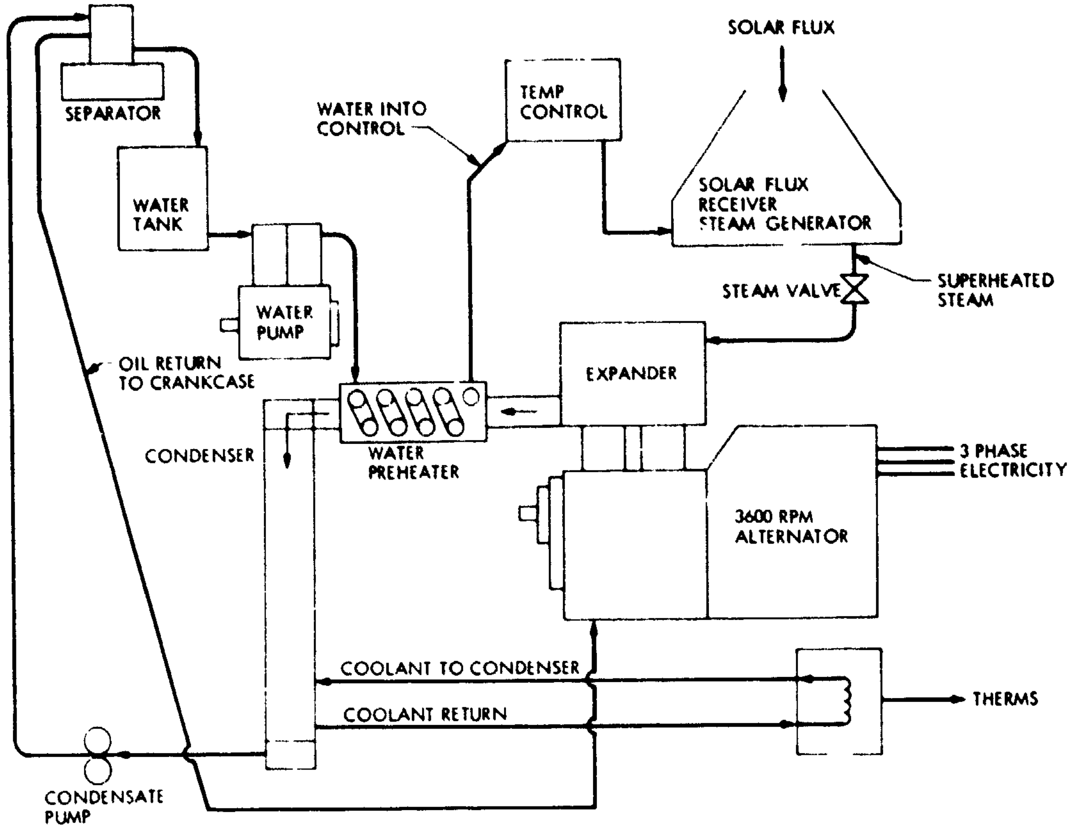

Figure 1. Power Module Schematic

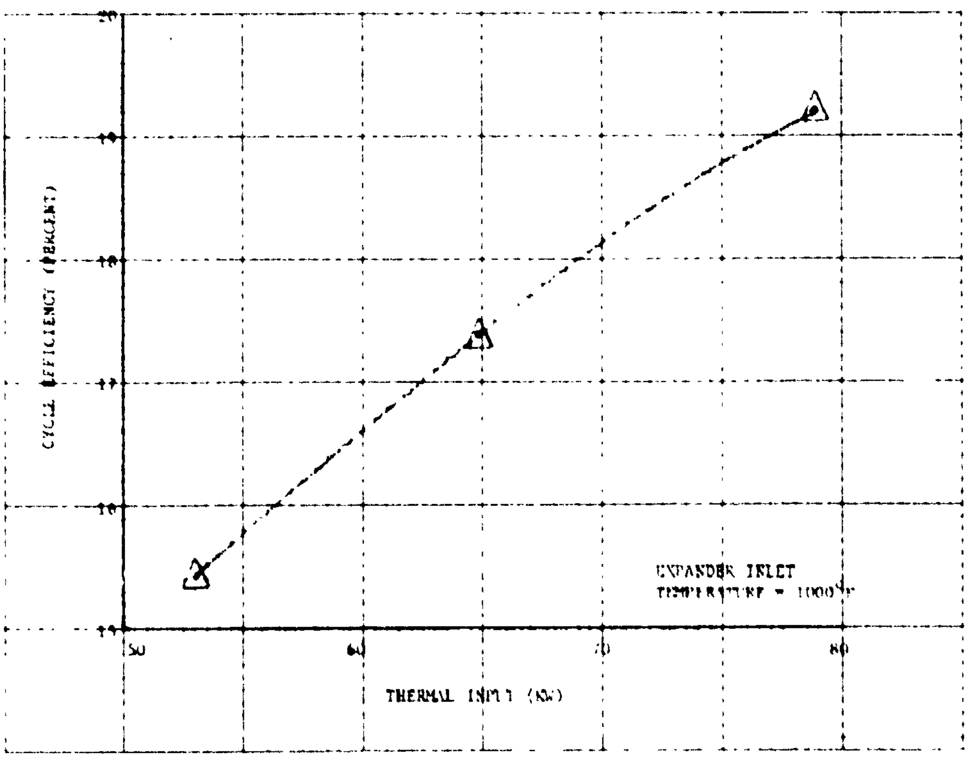

Figure 2. Preliminary Engine Data